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CAUSES OF DECADENCE IN THE OLD GROVES OF NORTH DAKOTA

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PROBLEM PRESENTED BY NORTH DAKOTA PLANTATIONS

The planting of shelter belts in eastern North Dakota dates from about 1870. Since the early settlement of the prairies, settlers have striven for trees to protect their homes from the blistering winds of summer and the cold blasts of winter, and to modify the monotony of the landscape. The original Timber Culture Act of 1873 was an effort to encourage such planting, but, according to present evidence, it was not remarkably successful. Most of the shelter-belt planting was apparently done around 1891, just before the later and less exacting Timber Culture Act was repealed that year, and was probably stimulated by the desire to complete the requirements of the act and "prove up" at the last minute. Thus, in 1931, a great many groves just about 40 years of age were found, only one in the 45-year class, and a gradually decreasing number down to about 25 years of age.

[1] Valuable assistance in collecting the field data for this study was rendered by Victor Freeman. Much credit is also due P. O. Rudolf and S. R. Gevorkiantz for aiding in the analysis of the field work. Special acknowledgment is made to Raphael Zon, C. G. Bates, and Charles E. Kellogg for their many helpful suggestions during the course of this study.

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In more recent years, both the Federal and State Governments have revived the effort to encourage tree planting in North Dakota, and with considerable success, by furnishing free suitable trees from their respective nurseries at Mandan and Bottineau. The resulting plantations are, however, too young to be considered in the present study.

Within recent years, according to the general observation, the trees of the old groves have been dying out much more noticeably, or rapidly, than has occurred previously. This fact has a discouraging effect on new planting. In the summer of 1931, therefore, the Lake States Forest Experiment Station undertook a study to determine the extent and causes of decadence in these groves. It was hoped that once the causes of failure were thoroughly understood changes might be suggested as to the kinds of trees and sites which should be planted, and the treatment which would assure the permanence and effectiveness of the plantations.

METHOD OF STUDY

The survey was carried on with two distinct objectives in view: (1) To examine in a general way as many groves as possible within a single field season, and (2) to study intensively a few groves with relation to survival, soil, species, and all related factors.

It should be clearly stated that, while in most groves an effort was made to determine the original spacing, the total number of trees in the initial planting was not used either in the intensive or extensive survey as a basis for estimating mortality. Too much of the mortality since planting may have been due to factors not now apparent. Therefore, counts were in all cases made only of living trees and the remains of those whose place in the stand was perfectly apparent. In general, farmers are reluctant to remove a dead tree until it is very evidently decaying, which may mean a delay of several years. Therefore, it seems probable that the mortality reported is that which has occurred in most cases in the last 7 to 10 years.

The extensive survey comprised 447 groves in Pierce, Benson, Ramsey, Wells, Foster, Eddy, and Stutsman Counties (fig. 1). Since both rainfall and the number of shelter belts decrease from east to west, it was deemed desirable to obtain an average of conditions, if possible, by locating the survey in the east-central part of the State. The Red River Valley was deliberately omitted, upon the belief that the somewhat greater rainfall in the extreme eastern part of the State has fostered the growth of better groves than is the rule for the State as a whole.

It was hoped that from this extensive survey a broad picture of the condition of the planted shelter belts in the area might be obtained—something in the nature of a statistical sampling of the situation. This part of the study was carried out through a roadside survey. All groves or windbreaks within 10 chains (660 feet) of either side of the road were included. The following information was taken for each grove: (1) Estimated percentage of living trees among those present, without distinction as to species; (2) number of rows planted, extent; (3) orientation of the long axis of the grove in regard to cardinal directions; (4) species; (5) estimated age; (6) estimated height; (7) spacing between trees; (8) classification of

the soil according to texture—light or heavy; (9) present policy in regard to grazing—grazed or not grazed; and (10) area of each windbreak. From 2.4 to 5.2 percent of the total area of each county was covered by this part of the windbreak study (table 1).

TABLE 1.—*Percentage of the total area of seven North Dakota counties covered by the windbreak study*

County	Total area	Area covered by the survey		County	Total area	Area covered by the survey	
	Acres	*Acres*	*Percent*		*Acres*	*Acres*	*Percent*
Benson	872, 960	21, 232	2. 4	Stutsman	1, 460, 480	43, 792	3. 0
Eddy	416, 640	10, 832	2. 6	Wells	827, 520	26, 864	3. 2
Foster	412, 160	21, 440	5. 2				
Pierce	675, 200	20, 240	3. 0				
Ramsey	771, 200	27, 008	3. 5	Total or average	5, 436, 160	171, 408	3. 15

By the intensive study of a few typical groves it was sought to establish specific relationships between mortality of the trees and the factors responsible for it. These groves were also used for accurate

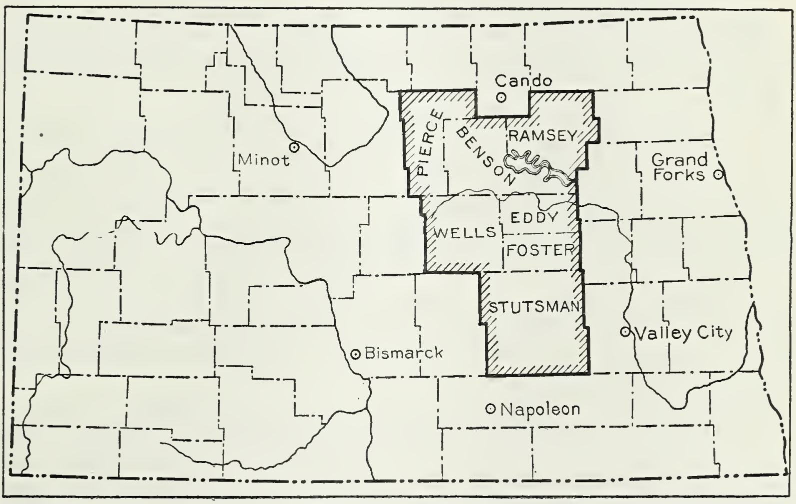

FIGURE 1.—Portion of North Dakota, enclosed by a heavy line, covered by shelter-belt study.

measurement of the sizes of trees. These sample areas were picked purely upon the basis of personal judgment as being somewhat typical of those of the respective counties. There may be some criticism of the study upon this ground.

A rather detailed analysis was made of these sample areas. The number of acres in the grove was determined, and a sketch made showing nearby buildings, fences, etc. All trees were tallied by species and 1-inch-diameter classes into three groups—dead, dying, and living. In those cases where the individual who had planted it could be located, the history and age of the grove were ascertained. The latter was always checked by determining the age of the trees themselves—the annual rings were counted on cores of wood taken from the base of the tree. The physicochemical character of the soil was investigated carefully in all cases. As the final step, heights

were taken of a few trees of each species in order to obtain a comparative measure of the productive capacity of the soil (site).

PHYSICAL AND CLIMATIC CHARACTERISTICS OF THE AREA

TOPOGRAPHY

All seven of the counties included in this study are located in that portion of North Dakota lying east of the Missouri River. Geologically, most of the area is classified as the drift-prairie region (*15*).[2] A small portion of the Missouri Plateau region is also represented. In some localities, as for example, in the northeastern part of Pierce County and the eastern portion of Eddy and Foster Counties, the gentle sweep of the drift prairie is broken by somewhat rolling morainic hills. In the southwestern part of Wells and the western part of Stutsman Counties the Missouri Plateau juts out and replaces the drift prairie. Here, too, the topography is very rolling. The elevation of central North Dakota ranges from 1,500 to 2,000 feet. The James and Cheyenne Rivers, flowing southeastwardly, drain most of the area.

CLIMATE

Unquestionably, the most decisive climatic factor in North Dakota is precipitation.[3] Moisture, or the lack of it, is a limiting factor in the growth of agricultural crops and trees alike.

Within the seven counties included in this study, the greatest part of the total area receives an average annual precipitation of 16 to 18 inches (fig. 2). Some small localities in the eastern part of Foster, Eddy, and Stutsman Counties get an average yearly total of slightly more than 18 inches, while an even more restricted locality in the western part of Pierce and Benson Counties receives a little less than an average of 16 inches annually. Drought years are common throughout the entire area. From 75 to 80 percent of the annual precipitation falls during the growing season, April to September, inclusive. The average annual snowfall is approximately 30 inches for the entire State.

Of even greater interest than the long-term precipitation averages, for purposes of the present study, is the degree of shortage which may occur, and has occurred most markedly in recent years. This is illustrated in the records of year-by-year precipitation quantities of 12 stations through the central section, since 1920,[4] as given in table 2. For purposes of comparison, the average for each station since it was established is given and also the averages since 1920 and 1925. These last two sets of averages bring out the fact that with the exception of Dunseith, Steele, Ashley, and Fullerton, a general shortage is indicated for the past 14 years, and, for eight stations, an even more marked shortage for the past 9 years, only partly compensated by the very good showing in 1927–28. Excluding 1932 and 1933 (the latter being the very worst of the entire series), the averages for these 12 stations show the year 1926 to have

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[3] Italic numbers in parentheses refer to Literature Cited, p. 32.

[3] All climatical data presented here are compiled from section 34 (western North Dakota) and section 35 (eastern North Dakota) of the Summary of Climatological Data for the United States, now in process of publication by the U. S. Weather Bureau. The sections cited are prepared as of 1930.

[4] This period is chosen for the beginning of the record because the upper Mississippi River and other streams of the northwest have shown a decided shortage of flow, almost without interruption, since 1920.

been the worst since 1920, while in point of number of stations showing some deficiency, up to and including 1931, the years 1925, 1926, 1929, and 1930 showed about equally complete occurrence of drought throughout this section of the State.

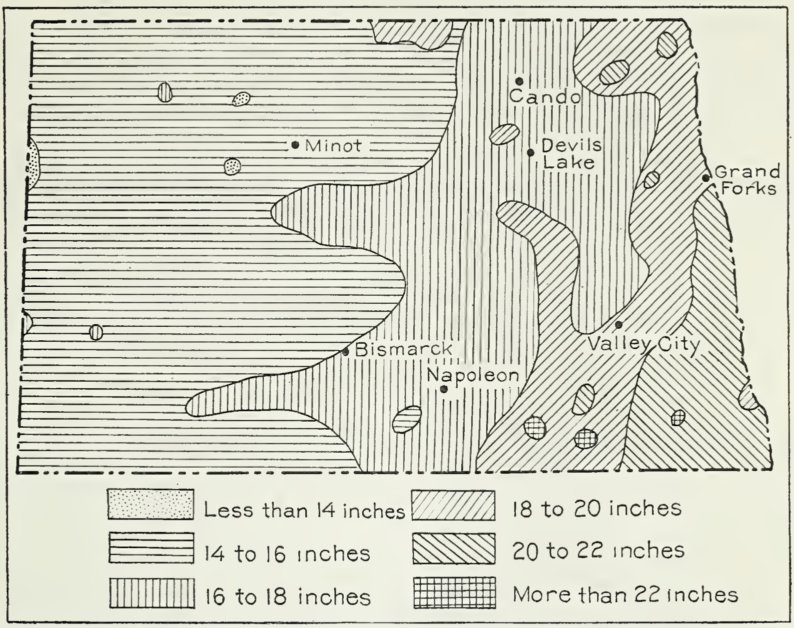

FIGURE 2.—Regional distribution of the average annual precipitation in North Dakota.

TABLE 2.—*Detailed record[1] of mean annual precipitation for 12 stations in central North Dakota with longest records,[2] 1920–33*

Year	Bottineau (42)	Dunseith (38)	Towner (32)	Manfred (31)	La Moine (29)	Jamestown (42)	Steele (40)	Bismarck (59)	Napoleon (42)	Fort Yates (34)	Ashley (38)	Fullerton (36)	Average
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1920	16.11	*9.88*	*11.47*	*14.73*	*13.36*	*16.83*	19.00	*11.15*	*14.37*	17.15	*18.00*	23.78	*15.49*
1921	18.38	18.36	18.66	25.41	17.60	28.45	*16.92*	*14.05*	*16.53*	*14.80*	30.42	28.57	20.68
1922	16.91	16.72	18.96	21.29	*15.25*	25.78	23.05	17.16	*14.50*	*14.76*	19.45	28.29	19.34
1923	19.46	17.60	*12.43*	*14.00*	*15.59*	21.51	21.15	*15.81*	18.21	18.29	23.42	25.50	18.58
1924	*13.53*	15.89	*11.27*	*16.26*	*14.00*	22.01	*15.99*	16.67	20.02	17.53	*17.95*	*19.16*	*16.69*
1925	*13.81*	*15.49*	*14.11*	*15.92*	*13.83*	*15.30*	*14.90*	*13.64*	*13.90*	*15.63*	22.35	27.44	*16.36*
1926	*14.62*	15.82	*12.81*	*13.25*	*12.52*	*14.83*	*17.92*	*12.37*	*14.24*	*14.31*	20.08	*20.42*	*15.27*
1927	20.49	21.37	23.13	21.97	25.88	25.79	28.18	20.84	26.01	21.28	20.86	32.12	23.99
1928	18.02	17.93	17.16	19.57	19.55	*15.43*	23.74	*16.02*	19.10	16.65	23.98	25.72	19.41
1929	*12.88*	*12.75*	*12.69*	*14.12*	*15.57*	*18.21*	18.17	*14.33*	18.24	*15.88*	*15.67*	*22.07*	*15.88*
1930	*13.46*	15.70	*11.11*	*14.18*	*14.30*	*14.13*	*17.96*	16.76	*15.49*	*16.59*	*17.79*	*21.76*	*15.77*
1931	*10.13*	*11.20*	*12.21*	*14.53*	*17.21*	*19.70*	18.25	*15.82*	20.25	*16.22*	19.08	*20.21*	*16.23*
1932	16.72	22.08	*14.64*	17.93	*15.44*	*19.69*	*13.60*	*14.41*	19.75	17.77	*18.57*	*22.30*	17.74
1933	*13.54*	*11.72*	*12.55*	*12.73*	*14.55*	*15.90*	*14.93*	*10.86*	*12.29*	*8.97*	*12.81*	*17.74*	*13.22*
Average to 1933 since establishment of station	15.85	15.56	15.72	17.55	17.40	19.92	17.97	16.34	17.59	16.65	18.96	22.99	17.71
Average 1920–33	15.58	15.89	14.51	16.85	16.05	19.54	18.84	14.99	17.35	16.13	20.03	23.93	17.47
Average 1925–33	14.85	16.01	14.49	16.02	16.54	17.66	18.63	15.01	17.70	15.92	19.02	23.31	17.10
Years below normal (number)	7	5	10	9	11	9	7	10	7	8	6	7	8

[1] Data obtained through the courtesy of and necessary interpolation made by C. W. Roberts, U. S. Weather Bureau, Bismarck, N. Dak. Yearly totals shown in italics are below the mean precipitation to date.
[2] Number of years of record indicated by figures in parentheses with name of station.

In describing the situation by means of these annual totals of precipitation the fact is not overlooked that distribution of the precipitation, in a region of high summer temperature and evaporation, may cause two apparently similar years to have radically different results in terms of vegetation—both trees and crops. This is especially important in a region which normally receives a large part of its precipitation during the growing season. There is, however, nothing in the way of more precise correlation which could be accomplished by going into the details of the records in this respect.

The really important thing, of course, is that with barely enough precipitation, even in the average year, to forestall semidesert conditions, an average deficiency of 0.61 inch, and an extreme deficiency of 2.26 inches per year at Jamestown, over a period of even 9 years, threatens very great depletion of the reserves of moisture, the recession of lakes which tend in some degree to modify the dryness of the atmosphere, and other similar cumulative effects.

North Dakota lies between 46° and 49° N. latitude and is characterized by hot summers and cold winters. Many years the temperature changes very abruptly in the springtime from a very low point to a high point. The yearly range in temperatures for several stations located in and adjacent to the area of study is given in table 3. Devils Lake is in Ramsey County, Carrington is in Foster County, Fessenden is in Wells County, and Jamestown is in Stutsman County. Maximum and minimum temperatures of 110° and −50° F., respectively, have been recorded officially over almost all of North Dakota, and the extreme northeastern portion of the State, together with adjacent northwestern Minnesota, has the coldest midwinter (January) climate of any part of the United States.

TABLE 3.—*Average temperatures for North Dakota*

Station [1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Within area of windbreak study:	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Carrington (31)	6.7	8.7	23.4	39.6	52.5	63.0	68.7	66.8	56.6	43.8	27.8	11.7	39.1
Devils Lake (29)	2.2	7.5	22.3	39.8	51.3	61.8	67.3	65.1	55.8	42.2	25.7	9.9	37.6
Fessenden (19)	4.5	10.1	23.4	40.7	52.0	61.7	68.0	65.9	55.7	43.0	27.1	10.6	38.6
Jamestown (38)	7.0	9.6	24.0	42.1	53.5	63.2	68.5	66.4	56.5	44.5	27.3	13.4	39.7
Outside area of study:													
Beach (24)	11.1	16.2	27.2	42.0	51.4	61.7	68.5	66.4	56.4	43.6	31.0	17.0	41.0
Bismarck (56)	7.8	10.3	24.2	42.1	54.5	63.7	69.8	67.3	58.1	44.9	28.5	14.7	40.5
Dickinson (38)	10.5	13.1	25.3	42.1	52.2	61.7	68.2	66.3	56.0	43.6	28.3	16.4	40.3
Garrison (33)	7.6	10.9	23.8	42.3	52.7	62.2	68.2	66.1	54.9	42.7	26.3	13.7	39.3
Grand Forks (40)	3.5	7.6	22.4	41.7	53.7	63.0	67.5	65.4	56.4	43.6	26.0	10.6	38.4
Minot (32)	6.2	9.7	22.8	40.8	52.2	62.3	67.9	65.0	55.9	43.3	27.5	11.9	38.8
Wahpeton (36)	8.4	12.0	27.5	44.4	55.6	65.1	69.8	67.9	59.2	46.6	28.8	15.3	41.7
Washburn (14)	7.4	9.5	24.4	43.8	53.8	64.1	69.5	67.4	58.5	44.5	30.3	14.0	40.6
Williston (51)	6.8	9.6	23.7	42.7	53.3	63.2	68.7	66.7	56.0	43.7	27.1	13.7	39.6
Willow City (37)	.9	4.9	19.7	39.6	51.5	61.0	65.7	63.6	54.2	41.4	22.6	8.7	36.2

[1] Figures in parentheses indicate length of record in years.

The average relative humidity in summer varies from 70 to 76 percent in the morning to as low as 20 to 25 percent during the hottest part of the afternoon. The total evaporation from a free water surface during the growing season (April to September, inclusive), sometimes amounts to as much as 33.0 inches (table 4).

TABLE 4.—*Evaporation from a free water surface at two North Dakota stations*

Month	Dickinson (24)[1]	Mandan (17)[1]	Month	Dickinson (24)[1]	Mandan (17)[1]
	Inches	*Inches*		*Inches*	*Inches*
April	3.711	3.668	August	6.535	6.577
May	5.127	5.447	September	4.329	4.462
June	5.964	6.077			
July	7.320	7.415	Total	32.986	33.646

[1] Figures in parentheses indicate number of years of record.

More than half of the days of the year are clear. During the period May 15 to July 31, 15 hours of sunshine may occur daily.

The average frost-free period is from late May to the middle of September.

Except where local conditions exert an influence, the wind is prevailingly from the northwest. The average year-round wind velocity for North Dakota is about 9.5 miles per hour.

SOILS

Next to climate, and more or less in conjunction with it, the physicochemical characteristics of the soil constitute one of the most important factors in the natural treeless condition of the prairies and the success and failure of artificial afforestation in this area. The prairie soils, therefore, receive considerable attention in this study.

Geographically, eastern North Dakota lies in the region of chernozemlike soils (*10*). The essential features of these soils are: (1) A dark-colored surface layer of varying thickness, rich in humic compounds, and usually neutral or slightly alkaline in reaction, and (2) underlying layers of lighter color, ordinarily rich in carbonates and strongly basic in reaction. The thickness and color of the several horizons or layers vary considerably with texture, the humus layer being somewhat thicker in sandy than in clayey soils.

With the possible exception of texture, probably the most important physical feature of the soils of east-central North Dakota is their structure during periods of extreme drought. In a general way two features characterize these chernozemlike soils in a dry state: (1) The surface or humus layer dries and bakes, so that cracks form, particularly in those soils having a high clay content, and (2) the upper part of the zone of carbonate accumulation becomes strongly compacted, forming a hardpanlike layer. A number of years ago, Weaver (*21*) observed these " pans " in Kansas and Colorado where they are found usually at a depth of 1.4 to 3.0 feet. He attributed their formation to the cementing effect of colloidal clay and carbonates and noted that the compactness disappeared when the soil became thoroughly moistened.

Generally speaking, the soils of east-central North Dakota are of a heavy clayey rather than a light sandy texture. Both the drying and cracking of the humus layer and the seasonal compactness of the soil appear to exert a considerable influence upon the root systems of planted trees. In the surface layer, some damage to feeder roots

is suggested by the physical stresses set up during drought periods, and it is quite possible that many tiny rootlets are broken or fractured by the cracking of the dry soil. The hardpanlike layer acts chiefly as a zone of delimitation, i. e., the roots can penetrate the compacted soil only with considerable difficulty. This is not to imply that roots cannot penetrate such layers, but rather that in dry periods there is little or no moisture to be found beneath them. Furthermore, a too heavy concentration of calcium may be repellent, if not absolutely toxic to the roots.

The occurrence of alkali salts is probably the most important consideration from the standpoint of planting and propagating trees. Hopper and Walster (*11*) have shown by chemical analysis of typical soils that they are generally high in carbonates, especially of calcium and magnesium. The silicon content varies considerably with texture and organic carbon content of the soil. Nitrogen, phosphorus, potassium, and sulphur ordinarily occur in quantities that are adequate for well-balanced plant growth. The alkali salt content of the soil varies with texture and drainage, considerable differences being shown with small changes of topography.

One of the interesting things brought out in the study of the soils of east-central North Dakota is their relatively high moisture content [5] even when the texture is quite sandy and drought conditions prevail.[6] Glinka [7] speaks of the high water-holding capacity and the poor capillarity of virgin loamy chernozem soil in the prairies of Russia, and Keller (*13*) concludes that the poor absorption, and high retention of water once absorbed, of the fine-textured soils characterizing the Russian steppes is one of the important factors contributing to the nonadvance of forests into the plains. He lists, as the other important checks, (1) injurious effects of soluble salts, (2) steppe fires, (3) sod competition, and (4) conditions unfavorable to the development of mycorrhiza on tree roots. How the characteristics of the chernozem soils of east-central North Dakota affect the survival and growth of forest prairie plantings is discussed throughout this report.

PRESENT CONDITION OF SHELTER BELTS

EARLY HISTORY

With the repeal of the Timber Culture Act in 1891, large-scale tree-planting activities came to an end in North Dakota. The final entry for the State under this act amounted to 1,226,606 acres; an additional 120,525 acres were commuted (*9*). Under the stipulations of the original act passed by Congress in 1873, a homesteader could acquire patent to 160 acres of land by planting one-fourth of it with trees, these to be spaced not more than 12 feet apart. An amendment, in 1878, reduced the size of the planted area from 40 to 10 acres, and specified that 2,700 trees per acre had to be planted, 675 of which must be living and thrifty at the time the patent was granted.

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[5] A detailed description of a number of typical prairie soils of east-central North Dakota may be found in the appendix. Some of the more important physicochemical peculiarities of these soils are also discussed.

[6] All soil studies were made during the months of July, August, and September in the extremely dry summer of 1931.

[7] GLINKA, K. D. THE GREAT SOIL GROUPS OF THE WORLD AND THEIR DEVELOPMENT. Transl. from the German by C. F. Marbut. 235 pp. Ann Arbor, Mich. 1927. [Mimeographed.]

Lack of enforcement spelled the doom of the Timber Culture Act in North Dakota, as elsewhere. All kinds of abuse and evasion of the regulations of the act took place. Old settlers tell of one practice of the time: a planting area was fall-plowed and sown with tree seed. The "planting" was witnessed and duly recorded. During the next spring the same area was tilled and planted with wheat.

Fortunately these breaches of faith on the part of the homesteader were not the rule. Many groves were planted well, tended properly, and nursed to maturity. They remain today as a proof of sincerity. Moreover, thousands of groves were planted by settlers bound by no legal obligation. These people planted trees because they had an appreciation of the value of shelter belts. Many of these groves also remain today as a living proof of pioneer initiative and foresight.

NUMBER OF GROVES PLANTED

The roadside survey through the seven North Dakota counties revealed more farmsteads with planted groves than without (table 5), since the 447 groves recorded comprised 65 percent of the 690 farmsteads included in this area. Of these farmsteads, 17.7 percent had a few scattered trees which were numerically too few to constitute groves, and another 17.5 percent had no forest plantation.

The 1930 census figures (*18*) indicate that at about the time of this study the average size of the farms in these seven counties was 496 acres. Assuming, as is believed to be essentially correct, that each farmstead encountered on the narrow strip survey represents such an area and with the average area of each grove 1.2 acres, it is readily seen that there must be, on the average, only 1 acre in every 638 acres which bears more than a few scattered trees, or in short, $\left\{\frac{447\times1.2}{690\times496}\right\}$ or 0.157 percent of the entire area.

TABLE 5.—*Number of groves and ratio of tree-covered to treeless land on 690 farms in east-central North Dakota*

County	Total area covered by survey	Total farms	Farms with groves	Treeless farm acres to each grove [1]	Ratio of treeless area to grove area	Farms with a few trees but no groves	Farms without trees
	Acres	*Number*	*Number*	*Acres*	*Percent*	*Number*	*Number*
Pierce	20,240	95	56	361	0.33	18	21
Ramsey	27,008	110	84	322	.37	12	14
Eddy	10,832	33	21	516	.23	5	7
Benson	21,232	61	31	685	.18	14	16
Wells	26,864	114	74	363	.33	21	19
Foster	21,440	90	66	325	.37	13	11
Stutsman	43,792	187	115	381	.32	39	33
Total or average	171,408	690	447	383	[2].31	122	121

[1] This includes only the acreage covered by a strip extending ⅛ mile on each side of the road traversed, and hence is not an adequate measure of the extent of each farm but is probably fair enough for comparing the relative conditions in different counties. The extensive survey showed that out of the total of 447 groves, 180 were less than 0.5 acre in area, and 267 were more than 0.5 acre in area. The average area of the last 142 groves examined, which was assumed for all, was 1.2 acres.

[2] According to figures found in the agricultural section of the Fifteenth Census of the United States, the wooded area in these 7 counties averages 0.71 percent of the total area. This apparent discrepancy can be accounted for in part upon the ground that these figures include natural as well as planted forest areas.

Table 5 while valuable for comparative purposes is somewhat misleading as to the acreage ratio, because the farmsteads and groves are generally located close to roads, and the width of strip was not

sufficient to include a proper proportion of the farm land on which no tree planting is done. There is, then, less than 0.16 percent of the total area of Pierce, Ramsey, Eddy, Benson, Wells, Foster, and Stutsman Counties devoted to the culture of tree crops. With such a small part of the total land area planted to trees, it is little wonder that no striking climatic or physical benefits can be claimed. If the area could be increased to 5 or even 10 percent, particularly if the groves were in the nature of long, relatively narrow strips, it is wholly possible that some very concrete climatic and physical benefits could be demonstrated, and any future planting program should emphasize this point.

KIND OF TREES PLANTED

Excepting the rare occurrence of evergreens, the tree species found in the groves of eastern North Dakota are 12 in number (table 6). Of this total, five species (aspen, American elm, boxelder, cottonwood, and green ash) are native to the area. The three willows and Russian-olive are exotics. Silver maple is not native to North Dakota (*12*), but is found in western Minnesota. Carolina poplar and northwest poplar are horticultural varieties of poplars native to the United States (aspen and cottonwood also belong to the poplar family).

TABLE 6.—*Occurrence of various tree species in 447 groves of east-central North Dakota*

Common name	Scientific name	Groves in which found	Common name	Scientific name	Groves in which found
		Percent			*Percent*
Boxelder	*Acer negundo violaceum* Kirchn.	73.6	Carolina poplar	×*Populus eugenei* Hort. ex Dode.	17.7
Cottonwood	*Populus sargentii* Dode.	64.4	American elm	*Ulmus americana* L.	1.0
Willows:			Aspen (popple)[1]	*Populus tremuloides* Mich.	1.0
European white	*Salix alba* L.	35.4	Northwest poplar	*Populus* spp.	.2
	Salix alba vitellina (L.) Willkomm and Lange.	16.1	Russian-olive	*Elaeagnus angustifolia* L.	.2
Bay	*Salix pentandra* L.	6.5	Silver maple	*Acer saccharinum* L.	.2
Green ash	*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.	25.7			

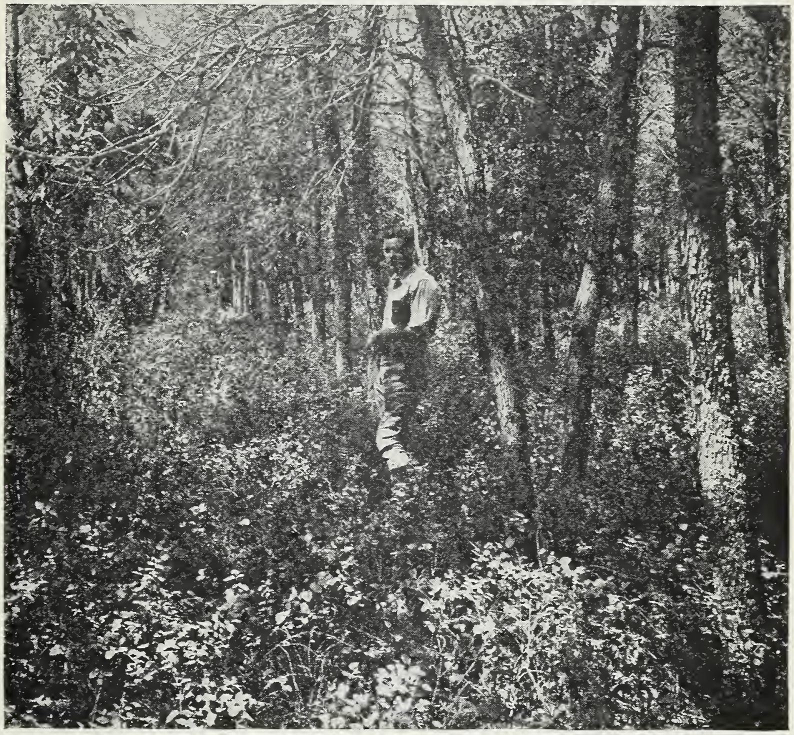
[1] There may be some question as to whether the aspen has been planted in these groves, or, its seed being wind-blown, it has seeded in from native trees of the area. In any event, aspen is not readily propagated by cuttings, as are nearly all other members of the poplar and willow families, and this should be borne in mind in connection with its later mention.

As might be expected, the native trees have been planted in groves more commonly than trees introduced into the area. The willows (European white and bay) are an exception. About 74 percent of all groves examined contained boxelder; 64 percent cottonwood; 58 percent willows; and 26 percent green ash. All other species were found in less than 25 percent of the total number of groves investigated during the course of this study.

MIXED PLANTINGS

In spite of the fact that only a few tree species were planted in the older groves of east-central North Dakota, the number of combinations formed by mixing these trees is quite large (table 7). Boxelder, cottonwood, willow, and green ash have been used most often in mixed plantings (figs. 3 and 4). Carolina poplar also has been

used extensively. There is some question as to whether these mixed stands are better than those in which only a single tree species has been planted. There seems to be at least one major advantage of hardwood mixtures—their several-layered character makes them more efficient as windbreaks than would be the case otherwise. The chief disadvantage of these mixtures in east-central North Dakota is that some of the species invariably die sooner than others. It was found, for example, that with rare exceptions green ash is less apt



F 259490

FIGURE 3.—Green ash and boxelder mixed by alternate rows. The average diameter of the ash is about 6 inches; the average height, 30 feet; the age, 40 years. Note the dense cover of western snowberry (*Symphoricarpos occidentalis* Hook.) under this stand. The boxelder are dying badly in the tops. This grove is located 3 miles west of Hamberg, Wells County, N. Dak.

to succumb to the rigors of the semiarid prairie region than willow. Consequently, a mixture of green ash and willow results in the earlier decadence of one species than the other. Such mixed groves have a ragged, unkempt appearance once the shorter lived species start to die. It must be admitted in all fairness, however, that a mixture of green ash and willow is more desirable than a pure plantation of the short-lived willow, since it is possible to cut out the dead willow and still have the green ash left. On the other hand, a plantation of pure green ash (fig. 5) would have lasted longer and looked better than the mixed grove of willow and green ash. Tillotson (*16*), a number of years ago, reached the conclusion that pure stands are generally preferable to mixed stands for farm plantations.

F 259507

FIGURE 4.—An open, grassy plantation composed of a 40-year-old mixture of green ash, cottonwood, boxelder, and white willow. This is a characteristic under-the-stand appearance for groves that have been subjected to a number of years' constant grazing. One mile north of Hamberg, Wells County, N. Dak.

TABLE 7.—*Species or combinations of species found in the groves of east-central North Dakota*

Species or combinations of species	Groves	
	Number	*Percent*
Boxelder, cottonwood, and white willow	80	17.9
Boxelder and cottonwood	58	13.0
Boxelder	36	8.1
Cottonwood	36	8.1
Cottonwood and white willow	32	7.2
Green ash, boxelder, white willow, and cottonwood	32	7.2
Boxelder and golden willow	25	5.6
Green ash, boxelder, and cottonwood	19	4.3
Carolina poplar, boxelder, and golden willow	11	2.5
Carolina poplar and golden willow	10	2.2
Boxelder and laurel-leaf willow	9	2.0
Green ash and cottonwood	8	1.8
Green ash, boxelder, and golden willow	8	1.8
Boxelder and Carolina poplar	7	1.6
Boxelder, Carolina poplar, and laurel-leaf willow	7	1.6
Green ash and boxelder	7	1.6
Green ash, Carolina poplar, cottonwood, boxelder, and golden willow	6	1.3
Green ash, Carolina poplar, cottonwood, boxelder, and white willow	5	1.1
Green ash, boxelder, white willow, and Carolina poplar	5	1.1
Green ash, boxelder, golden willow, and Carolina poplar	5	1.1
Green ash, laurel-leaf willow, and Carolina poplar	4	.9
Green ash and Carolina poplar	4	.9
Cottonwood, green ash, golden willow, and laurel-leaf willow	4	.9
Carolina poplar	3	.7
Carolina poplar and laurel-leaf willow	3	.7
Green ash, boxelder, and Carolina poplar	3	.7
Cottonwood, Carolina poplar, and white willow	3	.7
Green ash	2	.4
Golden willow	2	.4
Laurel-leaf willow	2	.4
American elm, boxelder, and cottonwood	2	.4
Cottonwood, Carolina poplar, and boxelder	2	.4
American elm	1	.2
White willow	1	.2
American elm, green ash, and boxelder	1	.2
Green ash, boxelder, Carolina poplar, and silver maple	1	.2
Green ash and golden willow	1	.2
Northwest poplar	1	.2
Cottonwood and Russian-olive	1	.2
Total	447	100.0

SPACING COMBINATIONS

A number of spacing combinations were observed in the groves of east-central North Dakota (table 8). The one most commonly used, which appears in about 38 percent of all the groves examined, was

F 259952

FIGURE 5.—A vigorous plantation of 20-year-old green ash near Devils Lake, N. Dak. The trees were pruned shortly before this picture was taken which accounts for the debris on the ground.

a spacing of 4 by 6 feet (trees 4 feet apart in rows spaced at 6-foot intervals). The second most common spacing, 6 by 8 feet, was used in approximately 24 percent of the groves. The remaining 38 per-

cent are distributed among 16 spacing combinations. For the purpose of future comparisons, these 18 spacing combinations are arbitrarily subdivided into two groups—those in which each tree has more than 40 square feet of initial growing space (wide spacing), and those in which each tree has 40 square feet or less of initial growing space (narrow spacing).

TABLE 8.—*Spacing combinations observed in the groves of east-central North Dakota*

Spacing (feet)	Growing space per tree	Groves		Spacing (feet)	Growing space per tree	Groves	
	Square feet	*Number*	*Percent*		*Square feet*	*Number*	*Percent*
Narrow spacings:				Wide spacings—Con.			
2 by 4	8	1	0.2	6 by 12	72	15	3.4
4 by 4	16	9	2.0	8 by 10	80	20	4.5
4 by 6	24	171	38.3	6 by 15	90	2	.4
4 by 8	32	27	6.0	8 by 12	96	8	1.8
6 by 6	36	11	2.5	6 by 20	120	2	.4
4 by 10	40	7	1.6	12 by 12	144	1	.2
Wide spacings:				8 by 20	160	1	.2
6 by 8	48	105	23.5	Irregular [1]		30	6.7
4 by 12	48	1	.2				
6 by 10	60	24	5.4	Total		447	100.0
8 by 8	64	12	2.7				

[1] Irregular spacing indicates that more than one spacing combination has been used in the grove.

OBSERVED EFFECT OF WINDBREAKS

The value of groves as a farm asset has been emphasized by several workers. Bates (*2*, *3*) has shown that in the central prairie States (Iowa, Kansas, and Nebraska) windbreaks materially reduced wind velocities and evaporation and increased crop yields within the zones of their influence. Waldron (*20*) emphasizes the aesthetic value of groves.

Actual observations carried on during the period from October 31, 1931, to November 30, 1932, at Towner, McHenry County, N. Dak., bear out the conclusion that even small shelter belts materially reduce wind velocities. Both instruments used for measuring the velocity of the wind were placed at a level 15 feet above the ground. The average wind velocity in a garden area protected on all four sides by a 2-rod-wide strip of 40-year-old cottonwood was 6.4 miles per hour for the entire period of observation. The second instrument, 500 feet north of the grove in an area receiving the full sweep of the wind at all times, registered 9.4 miles per hour for the same period of observation. This means that the wind velocity inside the grove was about two-thirds of that outside the grove. Naturally, these old cottonwoods with very few limbs near the ground are not nearly as effective in breaking the wind as younger trees or trees supported by outside rows of shrubbery.

The protection afforded to buildings by shelter belts depends also upon the location of the planted strips. This study shows that the groves have not always been located properly to afford the greatest protection from the prevailing wind from the northwest. Out of the total of 447 groves examined, 101 (22.6 percent) had been planted west of the farmstead; 115 (25.7 percent) north of the farm buildings; and 231 (51.7 percent) both north and west. This

latter arrangement naturally is to be preferred since it affords protection from all western and northern quarters. Then, too, the trees should not be too close to the buildings to be protected if the greatest benefit is to be had and if troublesome snow-drifting close to the trees is to be avoided.

There is some difference in the efficiency of various tree species for windbreak purposes. Bates (*2*) has shown that white pine is more than twice as efficient as cottonwood in reducing the velocity of a 15-mile wind at a distance of five tree heights from the lee side of a grove. Unfortunately, there have been practically no evergreen groves planted in east-central North Dakota. Much more study of the value of different species from every standpoint is certainly desirable. The entire subject of position, size, arrangement, and kind of trees in windbreaks is one which deserves a good deal of careful planning to fit the individual case, especially since, once the trees are planted, it is not easy to correct any mistakes made.

GRAZING

As a general rule, the planted groves of east-central North Dakota are extensively and intensively grazed, a practice which here includes the use of the groves for stock corrals. Unquestionably, such grazing use is the worst abuse to which the average grove is subjected. Not only are most groves very convenient overnight corrals, but they are also naturally attractive as a place of shelter both from heat and violent storms. About 45 percent (203) of the 447 groves examined during this study are now being used as enclosures for stock (cattle, horses, and sheep). Probably the majority of the 244 not being grazed at present actually have been so treated in the past.

Because of the obscure history of most of these groves, it is next to impossible to determine the exact relationship of grazing to deterioration. Some recent work has, however, been done. Day and Den Uyl (*6*) have concluded that under Indiana conditions the first step necessary for improvement of farm woods is the restoration of natural balances by the removal of livestock from such areas. Auten (*1*) found that there was a loss of porosity of the soil following the grazing of natural farm wood lots in the Central States region. He showed that—

> compaction accompanies grazing, and compaction means smaller water-holding capacity, poorer aeration, and general decrease in tilth and productivity. Trees become stag-headed where grazing is continued, litter largely disappears, sod forms, and the woods grow thin and finally disappear.

If this is true and important to the health of trees where the rainfall is 30 to 35 inches per annum, how much more important it must be when, at best, the trees can obtain scarcely enough water to survive! Considering that North Dakota soils are naturally very compact, grazing must have a bad effect on groves aside from preventing the accumulation of a natural mulch.

SIZE OF TREES IN OLD SHELTER BELTS

In the intensive study of 12 of the groves 37 to 44 years of age, the average of the tallest cottonwood trees was found to be 60 feet in

height and 11.7 inches d. b. h.[8] (table 9). Next to cottonwood, willow makes the most rapid growth of any of the trees commonly found in the older groves of east-central North Dakota. The largest willows were found to average about 44 feet in height and 9.1 inches in diameter. The tallest boxelders in these same groves average about 28 feet in height and 6.1 inches d. b. h. Similarly, the largest green ashes average about 32 feet in height and 5.3 inches d. b. h.

TABLE 9.—*Average diameter, breast high, and height*[1] *for the larger (dominant) trees of 12 planted groves in east-central North Dakota*

Plot	Age of grove	Cottonwood			Green ash			Boxelder			Willow [2]		
		Diameter	Height	Basis, trees	Diameter	Height	Basis, trees	Diameter	Height	Basis, trees	Diameter	Height	Basis, trees
Plot no.:	*Yrs.*	*In.*	*Ft.*	*No.*	*In.*	*Ft.*	*No.*	*In.*	*Ft.*	*No.*	*In.*	*Ft.*	*No.*
12	40	9.5	47	14	------	------	------	4.7	24	7	------	------	------
12b	40	10.1	58	16	------	------	------	6.6	30	4	7.7	47	5
10	42	11.1	55	7	------	------	------	------	------	------	------	------	------
11	37	11.2	54	16	------	------	------	4.8	22	7	------	------	------
3	43	11.2	56	5	2.5	15	5	------	------	------	------	------	------
12a	40	11.8	72	21	------	------	------	6.5	33	9	------	------	------
5	40	12.1	53	5	------	------	------	------	------	------	------	------	------
20	40	13.0	64	25	5.7	30	18	7.4	30	16	------	------	------
22	44	13.4	65	9	3.7	25	3	5.1	24	10	10.4	43	15
5a	40	14.5	61	6	------	------	------	------	------	------	------	------	------
22a	39	------	------	------	4.6	37	23	------	------	------	7.5	43	8
23	40	------	------	------	7.8	36	11	------	------	------	------	------	------
Weighted average	40.3	11.7	60	------	5.3	32	------	6.1	28	------	9.1	44	------

[1] This is total height as measured with an Abney level.
[2] Includes both *Salix alba* and *S. alba vitellina*.

Since boxelder, cottonwood, green ash, and willow are found in a high percentage of the shelter belts of east-central North Dakota, these species give character to the planted groves of the area, particularly when they are viewed from a distance. Upon closer examination of the groves themselves, the trees show a great variation in height and diameter. As a general rule, only a small percentage of the trees of any one species have a diameter and height which correspond with the average size of the largest trees. This is clearly brought out in tables 10 and 11.

On the basis of an actual tally of 7,277 healthy boxelder, cottonwood, green ash, willow, and aspen in these 12 groves (table 10), it is evident that out of every 100 boxelder trees only 19 have a diameter which corresponds to that of the average (6.1 inches) for the largest trees, and the average size of all boxelders is 4.5 inches d. b. h. Cottonwood shows the same trend—only 11 trees out of 100 are 12 inches d. b. h., while the average for all the groves is 9.8 inches. In the case of green ash, the range of diameters is scarcely less than that for boxelder, but considerably more than half the trees are grouped in the 4- to 6-inch d. b. h. classes, and the average for the largest trees hardly differs from the 5-inch average for all the trees. Willow resembles boxelder in its diameter spread from 2 to 17 inches, and in the fact that its average of 7.6 inches d. b. h. for all trees is

[8] D. b. h.=diameter at breast height, i. e., 4.5 feet from ground.

appreciably lower than the average for largest trees. Seventy percent of the aspen trees average 1.8 inches d. b. h., and 90 percent are in the 1- to 6-inch classes, with an average for all trees of 3.1 inches d. b. h.

TABLE 10.—*Percentage distribution of healthy trees by diameter classes for 12 planted groves in east-central North Dakota*[1]

Diameter at 4.5 feet above the ground (inches)	Boxelder	Cottonwood	Green ash	Willow	Aspen	Diameter at 4.5 feet above the ground (inches)	Boxelder	Cottonwood	Green ash	Willow	Aspen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	10.9	------	6.8	------	30.5	13	------	5.9	0.1	2.3	0.0
2	5.0	------	4.3	0.1	24.0	14	0.1	4.2	0.0	2.5	.2
3	13.8	0.2	9.8	6.4	16.0	15	------	2.1	.1	1.9	.1
4	17.3	1.2	15.8	11.0	9.9	16	------	1.8	------	.1	------
5	23.4	2.2	23.5	14.4	3.5	17	.1	.7	------	.3	------
6	18.6	7.1	21.4	12.4	6.1	18	------	.3	------	------	------
7	5.6	7.5	8.6	8.3	2.9	19	------	------	------	------	------
8	3.6	14.1	6.2	11.0	2.6	20	------	.1	------	------	------
9	.7	15.4	2.3	8.6	2.1	21	------	.1	------	------	------
10	.7	16.0	.8	7.3	1.2						
11	.1	10.4	.3	7.5	.4	Total	100.0	100.0	100.0	100.0	100.0
12	.1	10.7	0.0	5.9	.5						

[1] Percentage values are based upon 1,407 boxelder, 2,032 cottonwood, 1,300 green ash, 642 willow, and 1,896 aspen. Sometimes natural reproduction of boxelder and green ash comes in under the shade of the older trees. It is this reproduction which accounts for the relatively great number of trees in the 1-inch class. Aspen (popple) is seldom planted in the groves of east-central North Dakota. However, it does often come in naturally. Once started, aspen reproduces itself by root suckers which come up almost every year. As a result of this habit of reproduction, trees of all sizes and ages are found in these aspen clumps.

TABLE 11.—*Average total height in feet of several tree species commonly found in 17 groves of east-central North Dakota*[1]

Diameter at 4.5 feet above the ground (inches)	Boxelder[2]	Cottonwood[3]	Green ash[4]	Willow[5]	Diameter at 4.5 feet above the ground (inches)	Boxelder[2]	Cottonwood[3]	Green ash[4]	Willow[5]
	Feet	*Feet*	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*	*Feet*
1	*9*	------	9	------	12	*40*	63	42	49
2	13	------	17	21	13	*41*	66	*43*	50
3	17	*18*	23	26	14	*42*	68	*43*	50
4	21	*25*	28	30	15	*43*	70	*43*	51
5	24	32	33	34	16	*44*	71	------	52
6	27	38	36	37	17	46	72	------	52
7	30	44	38	40	18	------	73	------	------
8	32	49	40	42	19	------	74	------	------
9	34	53	41	44	20	------	75	------	------
10	36	57	41	46	21	------	76	------	------
11	38	60	42	48	22	------	76	------	------

[1] Values in italics are interpolated from curved known values. Measurements are taken from the 12 groves cited in tables 9 and 10 plus 5 more windbreaks 20, 29, 31, 33, and 43 years old, respectively. Because of this greater amount of basic data, average height and diameter values here given vary slightly from those in table 9 and are somewhat more exact.

[2] Curve values based on 69 trees; average diameter, 6.1 inches; average height, 27±0.84 feet; standard deviation in height, ±6.9 feet; standard error of estimate, ±3.9 feet; alienation index, 0.56.

[3] Curve values based on 137 trees; average diameter, 11.5 inches; average height, 59±1.0 feet; standard deviation in height, ±11.8 feet; standard error of estimate, ±7.9 feet; alienation index, 0.67.

[4] Curve values based on 95 trees; average diameter, 4.6 inches; average height, 29±1.1 feet; standard deviation in height, ±10.4 feet; standard error of estimate, ±6.1 feet; alienation index, 0.59.

[5] Curve values based on 33 trees; average diameter, 9.0 inches; average height, 42±1.9 feet; standard deviation in height, ±10.5 feet; standard error of estimate, ±7.8 feet; alienation index, 0.75.

The trees of the older shelter belts vary considerably, not only in diameter, but also in height. As a matter of fact, there is a definite relationship between the diameter of the tree and its height. This relationship is brought out very clearly in table 11. From this table it may be seen that in the older groves boxelders vary from 9

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to 46 feet in height, with an average height corresponding to the average diameter in table 10 of approximately 22 feet. Cottonwood ranges from 18 to 76 feet in height, with an approximate average height of 56 feet. Green ash ranges from 9 to 43 feet in height and its average diameter indicates an average height of 33 feet. Willow heights are from 21 to 52 feet, and the indicated average is 41 feet.

It must not be assumed that the values of table 11 will coincide exactly with the measured heights of trees in all cases. Actually, the height of trees of a given diameter and species will not always be the same. However, these averages are fairly good approximations. The statistical soundness of these approximations may be determined from the footnotes of table 11. Of the statistical values found in the footnotes, the alienation index, which in this case shows true effect of diameter upon height, should be mentioned. For example, the alienation index is given as 0.67 for cottonwood. This means that 55 percent of the variance of height of cottonwood is associated with diameter, and that the remaining 45 percent is independent of diameter but may be dependent upon other factors, such as the influence of spacing, soil, moisture, etc.

From this survey of the growth of different species in the older shelter belts, it is evident that cottonwood attains a larger size in both height and diameter than any other species. The next species in rapidity of growth is willow, with boxelder and green ash following.

If growth alone were the measure of success in shelter-belt planting, then groves composed entirely of cottonwood should be the most desirable. However, there are other factors that affect the permanence of a shelter belt. One of the most important of these factors is the adaptability of a given tree species to the climatic conditions of the area. This adaptability finds expression in the number of healthy trees in the older groves as compared to the number of dead or dying trees. Thus, the effectiveness of the shelter belts is measured not only by the rapid growth of a few trees that may survive the rigors of the climate, but also by the better survival of other species even though they may grow at a much slower rate. This is brought out more clearly later in a discussion of the decadence in the older groves.

THE RELATION OF TREE SIZE TO SOIL MOISTURE IN COTTONWOOD AND GREEN ASH GROVES

Soil moisture has been found to be one of the important factors affecting survival and tree growth in eastern North Dakota. During the course of the extensive survey, it was observed many times that cottonwood, boxelder, and willow showed their best survival and growth in natural depressions characterized by moist soil. It was observed that green ash, on the other hand, apparently did best on the less moist, better drained sites.

In order to obtain more definite proof of the effect of soil moisture upon tree growth, two groves were studied intensively. An analysis was made of the effect of soil moisture upon the growth of cottonwood in a shelter belt near Hamberg, Wells County. A similar investigation was made of the effect of soil moisture upon the growth of green ash in a plantation on the outskirts of Devils Lake, Ramsey County.

The cottonwood shelter belt consists of an interior block of cottonwood, about 2 acres in area and 40 years of age, protected on three sides (west, north, and east) by a narrow strip of boxelder, green ash, and willow. Except where the death of trees has left blank spaces, the trees are spaced 8 by 8 feet. A part of the area planted with cottonwood is situated on a knoll; the remainder, in a moist depression. Although the difference in elevation between these two areas amounts only to 22 feet, it exerts a decided influence upon the features of the soil profile, soil moisture, and tree growth.

COMPARISON OF SOIL PROFILES, SOIL MOISTURE, AND TREE GROWTH IN THE COTTONWOOD GROVE

Moist depression	Dry knoll
Horizon A_1	
10 to 11 inches of dark grayish-black loam; moist; loose, granular structure; completely invaded by tree roots; gives negative reaction with HCl. Soil moisture, at 5 inches, 35.7 percent of oven-dry weight.	3 inches of medium grayish-black loam; dry; loose, granular structure; considerable root development in this zone; gives negative reaction with HCl.
Horizon A'_1	
20 to 22 inches of dark grayish-black clayey loam; moist; friable, but weakly compacted; prismatic structure; pieces break easily into small crumbs when crushed in the hand; many roots are present; gives negative reaction with HCl. Soil moisture, at 15 inches, 20.9 percent of oven-dry weight.	9 to 10 inches of light yellowish-brown loam; dry; loose, granular structure; many roots occur in this layer; gives negative reaction with HCl. Soil moisture, at 5 inches, 8.8 percent of oven-dry weight.
Horizon B	
6 to 10 inches of dark yellowish-gray sandy clay; moist; prismatic structure; larger fragments break easily into small pieces; splotched with accumulations of dark yellowish-orange sand and gravel; reacts weakly with HCl. Soil moisture, at 40 inches, 19.9 percent.	11 to 12 inches of chalky white gravelly loam; very dry; very compact; granular structure; considerable root development in this horizon; reacts strongly with HCl. Soil moisture, at 15 inches, 7.1 percent.
Horizon B_1	
Absent.	6 to 8 inches of yellowish-gray gravelly loamy sand; dry; structureless; slightly cemented; reacts strongly with HCl. Soil moisture, at 30 inches, 7.2 percent.
Horizon C	
12 inches of dark yellowish-gray silty loam containing a little gravel; moist; slightly compacted; lamellar or platy structure (exhibits horizontal cleavage); when broken with the hand, fragments fall into numerous small flakes; mottled with small orange and black-brown agglutinations (shows glei processes have been at work); gives weak reaction with HCl. Soil moisture, at 50 inches, 10.9 percent.	15 inches of light yellowish-brown gravelly clay; moist; very compact; prismatic structure (large chunks can be broken out with a spade); small carbonate tubes are abundant; little root development in this horizon; reacts strongly with HCl. Soil moisture, at 50 inches, 10.2 percent.

Growth of cottonwood

Of 21 dominant cottonwoods measured, average diameter at breast height was 11.8 inches; average height, 72 (±2.4) feet.

Of 14 dominant trees measured, average diameter at breast height was 9.5 inches; average height, 47 (±1.8) feet.

It is evident from these data that (1) a difference of 22 feet in elevation affects the soil profile; (2) that there is an abundance of soil moisture in the natural depression; and (3) that cottonwood has made much better growth in the depression than on the hilltop. A statistical analysis[9] of these differences shows that they are significant. (See table 13.)

The trees in the green ash plantation are spaced extremely close (1½ by 4 feet). The grove has been well-tended and little grazing has been permitted. The plantation is approximately 225 by 425 feet, with the long axis in a north-south direction. Although the difference in elevation between the high (north) end and the low (south) end is not more than 5 feet, this gradient is sufficient to affect the soil profile, soil moisture, and tree growth:

COMPARISON OF SOIL PROFILES, SOIL MOISTURE, AND TREE GROWTH IN THE GREEN ASH GROVE

Well drained site (north end)	Poorly drained site (south end)
Horizon A_1	
10 to 12 inches of dark grayish-black loam; dry; pealike structure (original structure destroyed by cultivation); a zone of root concentration; gives no reaction with HCl. Soil moisture, at 7 inches, 15 percent of oven-dry weight.	6 to 7 inches of dark grayish-black loam; dry; granular to small nut structure (original structure somewhat modified by cultivation); most of the tree roots are concentrated in this horizon; gives negative reaction with HCl. Soil moisture, at 6 inches, 16.5 percent of oven-dry weight.
Horizon A'_1	
11 to 12 inches of dark brownish-black loam; dry; prismatic structure (the original structure may have been affected slightly by cultivation); this horizon contains numerous roots; gives negative reaction with HCl. Soil moisture, at 18 inches, 13 percent.	5 to 7 inches of dark grayish-black loam; in appearance this horizon differs from the A_1 in one particular—it contains a few funguslike threads of carbonate material; chemically it differs from the A_1 in that it reacts weakly with HCl. Soil moisture, at 15 inches, 13.6 percent.
Horizon B	
14 to 16 inches of yellowish-gray slightly gravelly clay; moist; prismatic structure; few roots occur in this layer; minute, vertical carbonate tubes are abundant; reacts strongly with HCl. Soil moisture, at 34 inches, 9.8 percent.	12 to 14 inches of yellowish-gray slightly gravelly clay; moist; prismatic structure; a considerable number of roots occur in this horizon; minute, vertical carbonate tubes are abundant; reacts strongly with HCl. Soil moisture, at 30 inches, 21 percent.

[9] The analysis was made in accordance with Fisher's *t*-test method (7).

Horizon C

At least 50 inches of dark yellowish-gray clay; moisture increases with depth; upper portion of this horizon has lamellar structure, lower part is wet, structureless clay; entire horizon is mottled with whitish-gray and deep reddish-orange agglutination (g l e i processes appear to be at work); carbonate tubes, abundant in the upper 18 inches of this layer, are absent in the lower portion; at a depth of 55 inches (from the surface) a 4-inch layer is encountered which is literally filled with milky white, translucent crystals (presumably magnesite or calcite); the entire C horizon gives a strong positive reaction with HCl but the strength of the reaction decreases with depth; there are no tree roots in this horizon. Soil moisture, 15 percent at 50 inches; 28.7 percent at 90 inches.

At least 60 inches of buff-colored clay; wet; sticky; structureless; contains innumerable yellow-orange and whitish-gray flakes or agglutinations (glei formations); also characterized by numerous accumulations of small, milky white, translucent crystals (presumably magnesite or calcite); no roots in this horizon; strongly reactive with HCl in the upper part of the horizon, less so with increased depth. Soil moisture, 24.8 percent at 50 inches; 46.6 percent at 88 inches.

Growth of green ash

Of 10 dominant trees measured, average diameter at breast height was 2.7 inches; average total height, 22 (±1.7) feet.

Of 10 dominant trees measured, average diameter at breast height was 1.6 inches; average total height, 12 (±1.0) feet.

Here again it is seen that rather small differences in topography have a marked influence upon the moisture content of the soil. The most significant thing brought out by these data is that green ash makes the best diameter and height growth on the better drained soils. Thus on poorly drained soil the average height growth has been only 12 feet in 20 years, as compared to 22 feet on the better drained soil. When these differences are tested statistically by the method used for the cottonwood grove they are found to be significant. (See table 13.)

It could well be added here that early observations made at the Denbigh Dunes Forest Experiment Station [10] indicate that the growth of green ash is not as good in low, poorly drained depressions as on the better drained, less alkaline upland situations.

CAUSES OF DYING OUT OF OLD PLANTATIONS

USE OF TREES NOT ADAPTED TO THE CLIMATE

The extensive survey of 447 groves confirmed the general opinion voiced by the farmers of the area that the old shelter belts are dying out. As a matter of fact, it was estimated upon the basis of this survey in 1931 that about one-fourth of the trees in the average grove, irrespective of species, had died (or were dying) so recently as to constitute a sharp rise in mortality (table 12). In order to determine more accurately the extent of this dying out, the intensive study of the 17 groves referred to in connection with table 11 was extended to include a tally of 14,664 aspen, boxelder, cottonwood,

[10] A field branch of the Lake States Forest Experiment Station, near Towner, McHenry County, maintained cooperatively with the North Dakota School of Forestry.

green ash, willow, and Carolina poplar (table 12). Of the 17 plantations 20 to 44 years in age, 12 were from 37 to 44 years. The extensive survey included 293 groves 26 to 40 years old, making a check between the two surveys quite feasible.

TABLE 12.—*Percentage of living, healthy trees in 17 groves 20 to 44 years of age*

Species	Trees examined	Living, healthy trees		Species	Trees examined	Living, healthy trees	
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
Aspen	2,153	1,896	88	Willow [1]	1,794	909	51
Green ash	4,161	3,549	85	Carolina poplar	291	15	5
Cottonwood	3,652	2,274	62				
Boxelder	2,613	1,628	62	Total	14,664	10,271	70

[1] Includes both *Salix alba* and *S. alba vitellina*.

As may be seen from table 12, 70 percent of all the trees included in the intensive study were living and healthy. By species, Carolina poplar shows the poorest climatic adaptability—95 trees out of every 100 were found to be dead or dying. Thirty-eight percent of the cottonwood and of the boxelder were likewise dead or dying. Green ash proved its ability to withstand the climatic extremes of the area as is evidenced by the fact that only 15 trees out of every 100 tallied were found to be dead or dying. Aspen made an even better showing with 88 trees out of 100 living and healthy.

From this tally of 14,664 trees,[11] it is clearly evident that Carolina poplar is poorly suited to the climatic conditions of the area, while aspen and green ash, which are both native species, are well fitted to survive under these conditions. Cottonwood and boxelder, also occurring naturally in the area along streams and lakes, are fairly well adapted for artificial plantings when sites similar to their natural conditions of growth are chosen.

The figures in table 12 indicate that the wrong selection of species, and particularly the use of species not adapted to the extremes of North Dakota climate, may be an important cause of the dying out of the older shelter belts.

SPECIAL SIGNIFICANCE OF THE RECENT DRY YEARS

The natural woody vegetation of a region represents that remnant of all of the species of neighboring regions which has been able to survive the ups and downs of climate (particularly the variations in rainfall) over a sufficiently long period of years to include all extreme conditions. It is almost an axiom that when a new tree species is tried in any region, it may thrive, especially if some cultural care is given, for a long period before some climatic extreme which is peculiar to the new situation occurs. For example, it is conceivable that such extremes of heat as occurred generally in the Northwest in 1931 may not have been felt for 20 years or more previously. It

[11] There was little opportunity during the course of this investigation to study the survival of evergreen trees. Actually, a single 17-year-old ponderosa pine grove near Devils Lake, Ramsey County, was examined critically. Although this pine plantation showed 100-percent survival, and seven of the largest trees averaged 3.7 ± 0.4 inches in diameter 4.5 feet above the ground, and 13.7 ± 0.9 feet in total height, no conclusions as to the climatic adaptability of this species are justified upon such meager data.

could be possible, then, to have plantations of more northern species, rather sensitive to heat, as much as 19 years of age, which had done very well up to that time but could not measure up to that particular test because no ancestor of these trees had ever experienced (or adapted itself to) that extreme.

In an area such as this which receives only 16 to 18 inches of rainfall normally, any year which is appreciably below the average may be considered a drought year. The balance is so critical here that unless the distribution is such as to favor vegetation during the growing season a shortage in precipitation of even 1 inch in a year may have marked effect on trees, and in any event is likely to cause some depletion of the small supply of moisture in storage in the ground. In the case of a wheat crop, the first year of shortage might seriously reduce the yield; if the drought were to persist, the wheat crop might be abandoned for a year and the moisture condition be more or less " caught up " by fallowing. No such thing is possible with the individual tree or grove of trees. A species that is very adaptable to drought conditions, such as green ash, can and does curtail to some extent its demand for moisture by losing its leaves unseasonably, but in the main, the tree is likely to be more or less seriously injured by the loss of its moisture supply, particularly during the growing season, and not to recover fully from such injury. Where the injury is repeated, the individual tree, or a certain percentage of the trees in a grove, is then permanently lost.

It is thus hardly to be questioned that the especially high losses which have caused alarm in recent years are due primarily to the most severe drought period since the nineties. Since drought is not preventable, and is likely to be severe enough in almost any single year for a grove of trees to deplete the moisture within its reach, the choice of species known to be adapted to these extreme conditions is, in North Dakota, an absolutely essential consideration. Furthermore, trees which in nature have proved long-lived under these climatic conditions have been found for the most part either along the stream bottoms and lake shores and in depressions where they receive extra moisture by seepage, or on the bluffs along the valleys where good drainage, leaching, and erosion tend to create more open soils than on the flat uplands. When planted somewhat away from these most favorable sites, native species should be aided in survival by cultivation, so that they may early benefit by the conservation of moisture obtained in closed, compact forest stands.

PLANTING ON THE LESS FAVORABLE SITES AND SOILS

Another factor which appears to be directly related to the decadence of the older shelter belts is the character of the soil in which they are planted. As a general rule, regardless of composition by species, shelter belts on light sandy soils tend to be lower in mortality than those on heavy clayey soils. This is probably due to the fact that moisture penetrates more deeply, and the trees are rooted more deeply in light porous soils. Heavy soils, moreover, may lose a portion of the precipitation by surface run-off.

It was also found that the present condition of groves in which the trees had been closely spaced (4 by 4, 4 by 6, 4 by 8, 4 by 10, and 6 by 6 feet) was better than that of groves in which wide spacing

(6 by 8, 6 by 10, 8 by 12 feet, etc.) had been followed. Apparently this is due to the fact that close spacing discourages grass and other vegetation from coming in and competing with the trees for moisture—a particularly important factor during the early life of the plantation. Wide spacing, on the other hand, encourages grass and other vegetation to spring up, and permits the leaf litter to be blown away and the wind and sun to have much greater potency in drying the soil.

An attempt has been made, following a method suggested by Lippett (*17*), to correlate statistically the observations made during the extensive survey which bear out these conclusions (table 13). Besides species, soil, and spacing there are other factors which, undoubtedly, contribute to the present decadence of the older groves, such as lack of proper care and grazing. While these factors are believed to play an important part in causing the death of the trees in older plantings, no direct statistical correlation could be obtained because no information was available in most cases as to the earlier treatment of the shelter belts.

TABLE 13.—*Effect of soil and spacing upon the decadence of the trees in 293 groves, aged 26 to 40 years*

Groves	Soil texture	Spacing [1]	Percentage of healthy trees	Computed t [2]	Index of significance [3]
Number					
17	Light (sandy)	Narrow	93.1	2.840	*1.15*
11	Light (sandy)	Wide	70.9		
141	Heavy (clayey)	Narrow	75.1	2.186	.94
124	Heavy (clayey)	Wide	69.7		
17	Light (sandy)	Narrow	93.1	3.968	*1.71*
141	Heavy (clayey)	do	75.1		
11	Light (sandy)	Wide	70.9	.172	.07
124	Heavy (clayey)	do	69.7		
Average			73.7		

[1] Narrow spacing is any combination which allows no more than 40 square feet of growing space per tree; wide spacing is any combination which allows more than 40 square feet of growing space per tree.

[2] t represents the ratio of the differences between mean percentages and the corresponding standard error of the difference, and is expressed by the formula:

$$t=\frac{M_1-M_2}{s\sqrt{\frac{1}{N_1}+\frac{1}{N_2}}}$$

where M_1 and M_2 are the two means, N_1 and N_2, the corresponding number of observations, and s, the square root of the variance, computed from the following expression:

$$s^2=\frac{Sum(m_1-M_1)^2+Sum(m_2-M_2)^2}{(N_1-1)+(N_2-1)}$$

Small m's denote individual observations. The denominator represents the number of degrees of freedom.

[3] Index of significance is equal to the ratio between computed t and the t obtained from Fisher's table for the 2-percent level of significance. Any ratio larger than 1.0 indicates that the difference between survival percentages is not due to the fluctuations of sampling alone, and that if the sample is replicated 50 times the same degree of significance would be obtained for 49 of the 50 replications. Values in italics are strongly significant.

Table 13 makes it clear that there are 28 groves between the ages of 26 and 40 years which occurred on light sandy soils. Of this number, the trees in 17 shelter belts were closely spaced, and showed an average estimated survival of 93 percent, i. e., 93 out of every 100 trees in the groves were living and healthy. On the other hand, the average estimated survival for the trees in the remaining

11 groves which are characterized by wide spacing was only 71 percent. Thus it is seen that on light soil narrow spacing has resulted in a healthier condition of older groves than wide spacing.

The next section of the table compares narrow and wide spacing for groves on heavy clayey soils. Here, again, it is seen that there is less decadence in narrow-spaced than in wide-spaced groves (75 as compared to 70 percent).

The influence of soil upon the present condition of the stand is brought out in the last two sections. When groves characterized by narrow spacing are compared on light and heavy soils, light soils show a marked superiority (93 to 75 percent). A similar comparison of groves in which the trees were spaced widely shows that there is little difference in the percentage of healthy trees on light and heavy soils (71 as compared to 70 percent).

The better survival in groves with trees closely spaced and in groves on light soil probably can be attributed to the thinner sod, and the quicker absorption and readier giving up of moisture characteristic of sandy soils.

The water table is ordinarily fairly close to the surface in light soils. In dug wells, the water table is encountered at a depth of about 7 feet in the sand-hill area of the Denbigh Dunes station. On the loams south of Webster, Ramsey County, the water table is reported by farmers to be from 10 to 25 feet below the ground surface, and at a depth of 12 to 15 feet in the sandy loam soils just south of Esmond, Benson County. In areas characterized by heavy clayey soils, wells are ordinarily 50 feet deep at least, and usually much deeper.

The differences in the decadence of groves on light and heavy soils were also subjected to a statistical analysis by the *t*-test formula. By this formula the significance of the difference between two means may be determined. The degree of strength of this significance is expressed here in the form of a ratio. If the ratio is 1.0 or more (see last column in table 13), the difference between the two means has real significance; if the ratio is less than 1.0, the relationship is not as strong.

For example, as can be seen from the fourth column of table 13, the difference in decadence between the denser groves on light and heavy soils is 18.0 percent (93.1 − 75.1 percent). When this difference is tested statistically the index of significance is found to be 1.71. This means that under conditions of close spacing, soil is a real factor in the present condition of the shelter belts. On the other hand, it was found that this relationship did not hold for groves in which the trees were widely spaced.

POSSIBLE IMPROVEMENTS IN SHELTER-BELT PLANTINGS

In the light of past experiences in shelter-belt plantings in eastern North Dakota and elsewhere, some definite suggestions can be made for the improvement of future planting practice.

A serious dying out of the trees in the old shelter belts is a fact well confirmed. This decadence, while probably speeded by the uncontrollable drought condition the past few years, is not, however, something that is inherent in forest planting, but is due in part to controllable causes. Had these causes been thoroughly understood

and eliminated at the time of planting, much of the loss which is now occurring in the older shelter belts would have been prevented. They are: (1) The use of species poorly adapted to the climatic conditions of the area, (2) wide spacing between planted trees which resulted in more competition from grass and other vegetation than would otherwise have been the case, (3) poor choice of planting sites, and (4) grazing and abuse of the plantings. All of these factors can be regulated or controlled.

Although there is little question that the groves on light soils are better on the average than those on heavy soils, it is not always possible to make the desired adjustments for this situation. This is particularly true in view of the fact that the prevailing soils of the area are clayey rather than sandy in texture.

CHOICE OF SPECIES

Of the broad-leaf trees, green ash, cottonwood, northwest poplar, and boxelder are the chief species to be favored in shelter-belt plantings. Green ash should be planted only on well-drained soils, while cottonwood, boxelder, and northwest poplar should be planted in moist depressions, and never on droughty slopes and hilltops. The trees should be spaced 4 by 4, 4 by 6, 4 by 8, 4 by 10, or 6 by 6 feet.

Although hackberry, white ash (*Fraxinus americana* L.), and Chinese elm (*Ulmus pumila* L.) were not found in any of the older groves, it is believed that these species merit more of a trial than has been given them so far in eastern North Dakota. Hackberry is a native tree and has been observed growing as far west as the sand hills of McHenry County; there is every reason for believing that this species is climatically adapted to eastern North Dakota. White ash already extends well into western Minnesota and therefore gives promise of doing as well somewhat farther west. Chinese elm is growing well at the experimental station of the Bureau of Plant Industry at Mandan, N. Dak., and has as good a record in a number of other places in the eastern part of the State.

Very few evergreen shelter belts were observed during the course of this study. The idea that it is next to impossible to grow them in the prairie is pretty general. While it cannot be said that evergreens are propagated as easily in east-central North Dakota as broad-leaved hardwoods, it appears that the difficulties of growing them there have been overemphasized (figs. 6 and 7). Inasmuch as they are more effective as windbreaks than broad-leaved trees and add considerably to the general appearance of a farmstead, it is hoped that more of an effort will be made to plant the following species: (1) On well-drained soils—the Rocky Mountain form of ponderosa pine (*Pinus ponderosa scopulorum* Engelm.), Scotch pine (*P. sylvestris* L.), and Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.); (2) on more moist sites—western white spruce (*Picea glauca albertiana* (S. Brown) Rehd.) and blue spruce (*P. pungens* Engelm.). It is also believed that a number of trial plantings should be made of northern European and Asiatic forms of larch, especially Korean larch (*Larix dahurica* forma *koreensis* Turcz.), European larch from the western Alps (*L. europaea* DC.), and Siberian larch (*L. sibirica* Ledeb.). Larch has been found to be a very good species for the northern prairie regions of Russia (*19*).

PLANTING IN STRIPS

It is believed that in the future all plantings should be in the form of relatively long strips about 100 feet wide, rather than small compact blocks as in the past. These strips break up the continuity

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FIGURE 6.—A 20-year-old jack pine (*Pinus banksiana* Lambert) plantation growing on a sand dune in McHenry County, N. Dak. Three of the largest trees measured 4.7, 6.0, and 6.7 inches, respectively, in diameter at a height of 4.5 feet above the ground. Their average total height was about 25 feet.

of the prairie and by doing so exert a maximum influence upon such climatic factors as wind velocity, air temperatures, air humidity, evaporation, etc. Figure 8 shows four methods of breaking up 640 acres of land with planted strips.

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FIGURE 7.—Wind-blown though it has been, this very small plantation of 25-year-old Scotch pine in Wells County, N. Dak., has made fair growth. The average diameter 4.5 feet above the ground was 6.8±0.5 inches for eight of the largest trees; the average total height for the same trees was 23±1.2 feet.

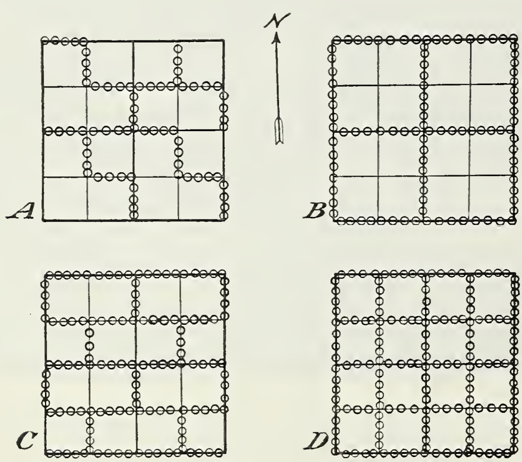

FIGURE 8.—Four methods of breaking up the continuity of the prairie with planted forest strips. Each of the four blocks has an area of 640 acres, and strips are in every case 99 feet wide. Small circles superimposed over "forty" lines show the location of planted strips: *A*, 4¼ miles of strip covering 51 acres or 8 percent of total area; *B*, 6 miles of strip covering 72 acres or 11.2 percent; *C*, 7½ miles, 90 acres or 14.1 percent of area; *D*, 10 miles, 120 acres, 18.8 percent.

PREPARATION OF GROUND

Ordinarily 2 years will be required to put sod areas in good planting condition. According to Wilson (*22*), areas to be planted with trees should be plowed in the spring the year before planting is to be done, to a depth of 6 to 8 inches, kept free from weeds during the ensuing summer months, and cultivated and leveled off smoothly in the late fall. The soil should not be tilled the following spring prior to planting.

CULTIVATION

Of fully as great importance as the preliminary preparation of the soil is the subsequent cultivation of the young plantations. Cheyney (*4*) reaches the conclusion that about the only sound basis for classifying the groves in the Minnesota prairie region is upon the history of cultivation in them; i. e., whether they have been well cultivated or poorly cultivated. He also found that good cultivation increased the growth of most tree species in younger plantations by 10 to 50 percent.

There is little doubt that cultivation is extremely important and that it should be continued at least 3 or 4 years, or long enough to insure the establishment of the young trees and the elimination of competing sod.

GRAZING

All livestock should be excluded from windbreaks, since grazing and trampling destroy the natural forest conditions. A number of large, ungrazed shelter belts were observed in east-central North Dakota. Although there were often many dead or dying trees in these planted groves, they were, in general, healthier than severely grazed plantations in the same general locality. Oftentimes, too, an abundance of natural reproduction of green ash and boxelder had come in on blank spaces left by the death of older trees. This suggests that to some degree, at least, these ungrazed plantations may be self perpetuating. Gates (*8*) observed that there was even some natural seeding-in of pine in the Kansas prairie sections. Usually " the seedlings came in on the north side of the shelter belts where the shade cast throughout the year has thinned the prairie somewhat."

Grazing also results in a reduction of the soil porosity and water absorption capacity. Considerable damage to young plantations may be done, too, by the barking of limbs and boles of the trees. In light of these known facts, there seems to be little doubt that the grazing of shelter belts is a very unwise practice, and that all forest plantations should be fenced permanently against livestock.

THINNINGS

When spacing in plantations is as close as 4 by 4 feet or 6 by 6 feet, the stand will ordinarily become crowded in 15 to 20 years and should be thinned. The only rule necessary for these thinnings is to take out enough trees to prevent overcrowding but in no case to open up the windbreak so much that grass and other vegetation is encouraged to come in. It is self-evident that deformed, diseased, badly stunted, or dead trees should be cut first. Fast-growing, light-

demanding species, like cottonwood, should be thinned more heavily than slower growing, more shade-enduring species like green ash.

PESTS

Jack rabbits commonly do considerable damage to young plantations in the Great Plains area. Sad experience has proven that the control of these pests is not particularly easy. Oftentimes they are too wary to be killed with poisoned bait. Moreover, there is the danger of poisoning creatures other than rabbits. Fencing with so-called " rabbit-proof " wire netting is not popular because of the cost. Then too, rabbits often dig under these fences, or go over the tops of them on snowdrifts during the winter months.

When all things are considered, there probably is no better method of getting rid of an excess rabbit population than by organized neighborhood hunts and drives. Late winter and early spring is the best time to conduct these hunts, since at this time there is usually a market for both the carcasses and pelts.

CONCLUSIONS

The planted groves in east-central North Dakota, from 15 to 40 years of age, contained in 1931 about 30 percent of dead and dying trees. This figure does not, of course, include trees which may have died much earlier, where in some cases a much larger percentage may have been reached. This 30 percent probably represents the losses over a period of 7 to 8 years.

The rather heavy recent loss has probably been the immediate result of the series of drought years starting in 1925 and continuing, with only slight abatement in 1927 and 1928, through 1933.

Practically all soils of east-central North Dakota are made more difficult for trees by a superabundance of lime. This acts in many cases by forming a partial hardpan at a relatively shallow depth and preventing free, deep penetration of tree roots. In lighter soils this layer is leached down to a greater depth.

The greatest current loss among trees commonly planted in the early days, as recorded in 17 test groves, is 95 percent for Carolina poplar (× *Populus eugenei* Hort. ex Dode), 49 percent for willows, 38 percent for boxelder (*Acer negundo violaceum* Kirchn.) and for cottonwood (*P. sargentii* Dode), 15 percent for green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.), and 12 percent for aspen (*P. tremuloides* Mich.).

Since the greatest mortality occurred in fast-growing species not native to the region, it is evident that half of the problem has been created by the choice of species not suited to the extremes of the North Dakota climate.

Since the species that have most commonly been planted in these groves are variously adapted to unfavorable conditions of soil moisture, those which require greater moisture may succeed for a few years but, naturally, will die on dry sites or in extremely dry years. This explains the failure, where they have been planted on dry hilltops, of cottonwood, boxelder, willows, and Carolina poplar, all of which are suited only to stream banks and bottoms.

Similarly all of the species commonly planted survive better on the lighter soils, where moisture and physical conditions are generally

more favorable, than on the heavy clay soils. However, some species are more adaptable to these soil differences than others, and green ash, for example, does well under a great variety of conditions.

Wide spacing, by encouraging the growth of grass, the removal of humus by the wind, and more direct drying of the soil, has apparently brought about a higher current rate of mortality in the recent drought years than occurred in groves in which the space per tree was 40 square feet or less (6 by 6 feet, 4 by 10 feet, etc.).

Groves which have been grazed, burned over, or otherwise abused, generally show a somewhat poorer survival than groves properly cared for, in which a semblance of natural forest conditions has developed. This statement is made despite the fact that no quantitative measure of the differences between well and poorly cared for plantations can be presented in proof.

Many of the species commonly planted in North Dakota groves are naturally short-lived. All of the poplars (the cottonwood least of all), after reaching a certain age, become susceptible to the canker disease. Under favorable conditions even cottonwoods and boxelder may survive much longer than 40 years, but under unfavorable conditions only temporary benefit can be expected from the planting of these "flimsy" short-lived species.

Although disease, insects, etc., may be a factor in occasional instances, death must be ascribed largely and primarily to the adverse climatic and soil conditions against which the trees have struggled. Of all the natural enemies of trees, jack rabbits are probably the most serious, often making it practically impossible to get young trees started.

Of the broad-leafed trees, green ash on well-drained soils, and aspen (popple), boxelder, and native cottonwood on lowlands, or in moist depressions, are the chief species to be favored in planting. The hardiness of green ash under the most extreme conditions of the Plains has been demonstrated in many places and periods.

There are other hardwood species, such as the native hackberry (*Celtis occidentalis* L.), white ash (*Fraxinus americana* L.), American elm (*Ulmus americana* L.), Chinese elm (*U. pumila*), bur oak (*Quercus macrocarpa* Mich.), and Russian-olive (*Elaeagnus angustifolia*), which hold out promise of success in North Dakota planting. As a general rule, the slower growing species are most likely to endure, and a species with a strong tendency toward taprooting has every advantage on the drier sites.

Of coniferous or evergreen species, which are encountered practically not at all in the older plantations, there are a few of considerable promise. Of all of these, Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.) is probably best adapted to limey and heavy soils. For dry, well-drained sites (preferably not too heavy or too limey soils) the Rocky Mountain form of ponderosa pine (*Pinus ponderosa scopulorum* Engelm.) and some varieties of Scotch pine (*P. sylvestris* L.) may succeed. In moist depressions blue spruce (*Picea pungens* Engelm.) and western white spruce (*P. glauca albertiana* (S. Brown) Rehd.) and probably some species of Korean or Siberian larch (*Larix dahurica* and *L. sibirica*) are the most hopeful. The larches have succeeded well on the northern prairies of Russia. The Lake States Forest Experiment Station, in cooperation with the

State forester of North Dakota, proposes to conduct systematic trials of all possible species.

Most of the conditions which are important in causing the death of older groves in North Dakota, except drought, can be controlled by man. The drought of the last 7 years, if it indicated a permanent change in the climate, might make future planting very difficult. If, however, this has been merely a low phase of a climatic cycle, and if mistakes of the past are avoided, the planting of windbreaks may prove as successful as in other prairie regions.

Future planting, in order that it may be of greatest benefit to the climate and living conditions of the region as a whole, should take the form of belts of trees, rather than of solid blocks. This does not mean single rows, or even strips a few rows wide, but rather windbreaks at least 5 rods wide. Narrower belts can hardly insure either protection or good growing conditions. The effect must be to establish a sufficiently massive formation to insure the most favorable conditions for the survival of the trees. Both protection and good growth will always be more certain where low, bushy species are used in the outside rows, to break the wind near the ground as the timber trees become taller and more open. This is an excellent place for red cedar, although its tolerance of shade makes it feasible also for use in underplanting groves that are too thin.

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APPENDIX

TYPICAL SOIL PROFILES [12]

From the standpoint of tree growth, both topography and climate find their final expression in the character of the soil. Because of this fact, soil plays an extremely important role in the propagation and growth of windbreaks in the northern Plains area. Inasmuch as this investigation probably marks the first attempt to study thoroughly the soils of the American Plains area in relation to the mortality and growth of the older forest plantations, the following detailed descriptions of these chernozemlike soils are fully justified.

LIGHT-TEXTURED SOILS

Profile 8.—Ten miles due east of New Rockford, Eddy County, N. Dak. Undisturbed prairie conditions. Level topography; 9 to 11 inches of dark grayish-black loamy sand; moist; loose, granular structure; much penetrated with grass roots; no reaction with HCl until a depth of 10 inches is reached; 16 to 18 inches of light grayish-black sandy loam; transition horizon as shown by the presence of vertical tongues of both dark grayish-black humus accumulations and grayish-white carbonate streakings; moist; slightly prismatic structure; material from humus tongues gives a positive but not strong reaction with HCl; material from carbonate tongues reacts strongly with HCl; 10 to 11 inches of dark yellowish-gray loamy sand; moist; structureless; some grass roots penetrate to the bottom of this horizon; a zone of carbonate accumulation; material from this horizon reacts strongly with HCl; 10 to 15 inches of yellow-

[12] When a vertical cut is made down through the soil layers, or horizons as they are called here, the surface soil and the subsoil can be viewed in their natural state. This vertical face is called the profile of the soil.

ish-orange sand and small-sized gravel; moist; structureless; reacts faintly with HCl; no grass roots occur at this depth.

Profile 11.—Three miles south of Esmond, Benson County, N. Dak.; 25 feet from the border of a 30-year-old cottonwood grove. Level topography; 10 inches of medium grayish-black sandy loam; moist, loose, granular structure; thoroughly invaded by grass and tree roots; gives no reactions with HCl; 17 to 18 inches of light yellowish-brown loam; moist; prismatic (large nut) structure; friable; much penetrated with roots; gives no reaction with HCl; 10 to 11 inches of grayish-white sand and gravel; dry, structureless, but with some degree of compactness; small white growths of calcium carbonate are extremely abundant; reacts violently with HCl; 31 to 33 inches of yellowish-gray sand; moist; structureless; some tree roots get down into this horizon; material from this layer reacts strongly with HCl.

Profile 10.—Two miles east of Churchs Ferry, Ramsey County, N. Dak. Taken in a 40-year-old cottonwood grove. Level topography; 2 inches of an admixture of partially decomposed hardwood litter and sandy loam; dark grayish-black color; moist; much penetrated with roots; 15 to 16 inches of medium grayish-black gravelly loamy sand; moist; friable, granular structure; completely invaded by tree roots; gives no reaction with HCl; 17 to 18 inches

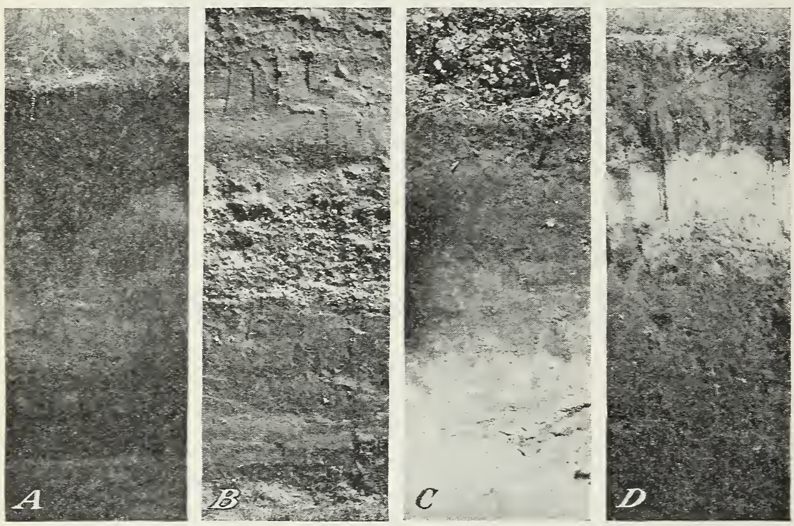

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FIGURE 9.—Typical chernozemlike light-textured soils of east-central North Dakota.

of medium blackish-brown sandy loam; streaked with fine white vertical calcium carbonate "threads" or growths; dry; compact; soil mass breaks into small clods or large nuts (prismatic structure) when shaken from a spade; faintly reactive with HCl; considerable root development in this horizon; 13 to 15 inches of yellowish-white gravelly sand containing small pockets of orange-colored sand and large vertical tongues of white calcium carbonate accumulations. Dry; compact; structureless. Few roots invade this horizon. The horizon as a whole is moderately reactive with HCl; the lime tongues give a violent reaction; 11 inches of orange-yellow coarse sand. Moist; structureless; moderate reaction with HCl.

Profile 13.—Two miles south of Harvey, Wells County, N. Dak.; undisturbed prairie soil. Slightly undulating topography; 7 to 8 inches of dark grayish-black loam; dry; loose, granular structure; completely invaded with grass roots; gives negative reaction with HCl; 4 to 5 inches of medium yellow-brown loamy sand; dry; compact, cloddy (prismatic) structure; larger fragments break with little difficulty into medium-sized granules; grass roots are numerous; gives negative reaction with HCl; 11 to 12 inches of chalky yellowish-white calcareous loam; dry; fine cloddy (prismatic) structure; larger fragments, when crushed in the hand, break easily into fine granules; grass roots

are common in this horizon; strongly reactive with HCl; 28 to 30 of medium brownish-yellow (almost buff) gravelly loam; moist; compact; cloddy (prismatic) structure; larger fragments can be crushed easily in the hand and fall into fine granules; small vertical pores are extremely numerous; gives a positive, though not strong, reaction with HCl; 10 inches of yellowish-gray coarse sand; dry; structureless; reacts faintly with HCl.

HEAVY-TEXTURED SOILS

Profile 9.—Seven miles north of New Rockford, Eddy County, N. Dak. Taken in a 35-year-old green ash grove. Level topography; 1 inch of undecomposed hardwood twigs and leaves; 8 to 9 inches of dark grayish-black loam; moist; granular structure; completely invaded by tree roots; gives no reaction with HCl; 15 to 16 inches of light grayish-brown gravelly loam; moist; prismatic structure (large nuts or small clods); does not react with HCl; 8 to 9 inches of yellowish-white gravelly clay; dry; compacted to a "panlike" consistency; exhibits horizontal cleavage (lamellar or platelike structure); reacts strongly with HCl; a few roots invade this horizon; 15 to 18 inches

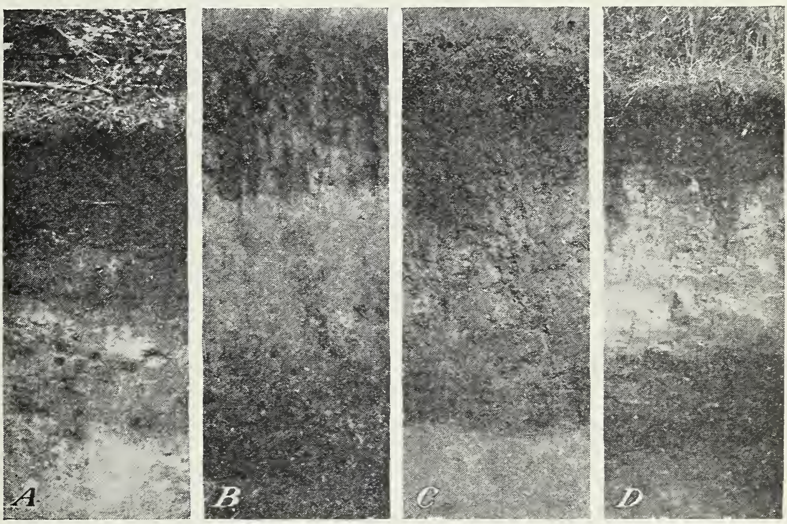

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FIGURE 10.—Typical chernozemlike heavy-textured soils of east-central North Dakota.

dark grayish-white gravelly clay; moist; strongly compacted; exhibits horizontal cleavage (lamellar or platelike structure); reacts strongly with HCl.

Profile 14.—Eight miles north of Hurdsfield, Wells County, N. Dak. Undisturbed prairie soil. Rolling morainic topography. Profile located on the crest of a hill; 5 to 6 inches of dark grayish-black loam; dry; loose, granular structure; thoroughly invaded with grass roots; gives no reaction with HCl; 7 to 8 inches of dark yellowish-brown silty loam; soil mass filled with minute vertical tubes; compact; breaks with difficulty into granules and small, medium, and large clods (prismatic structure); completely invaded by grass roots; gives negative reaction with HCl; 14 to 15 inches of yellowish-white gravelly silt loam; moist; loose; large fragments crush easily into large and small granules; reacts strongly with HCl; 20 to 23 inches of dark yellowish-gray slightly gravelly clay; deep orange and blue-gray flakes suggest glei processes; compact; falls from the spade into fragments one-half to 2 inches as measured on the longest axis (prismatic structure); fragments crush with no great difficulty into moist, clinging granules; gives a positive though not strong reaction with HCl.

Profile 15.—Eleven miles west of McClusky, Sheridan County, N. Dak.; undisturbed prairie soil; rolling morainic topography; profile located on the crest of a hill; 7 to 10 inches of dark grayish-black loam; dry; upper 3 inches

exhibits a loose, granular structure; lower 4 to 7 inches is not so friable and has a prismatic structure; larger fragments crush easily into granules; a zone of root concentration; gives negative reaction with HCl; 23 to 24 inches of grayish-yellow calcareous clay; moist; soil mass falls from the spade into prismatic fragments one-half to 4 inches long; fragments can be crushed with difficulty in the hand, breaking into small nutlets and various sized granules; very compact; little root development in this horizon; strongly reactive with HCl; 10 inches of dark brownish-gray clay; moist; prismatic; so compact that excavation with a mattock is difficult; soil mass falls from the spade in fragments measuring 5 to 6 inches along the major axis; fragments can be crushed with difficulty in the hand into various sized nutlets and granules; no roots invade this horizon; gives a positive reaction with HCl.

Profile 5.—Two miles south of Webster, Ramsey County, N. Dak. In a somewhat unshaded portion of a 40-year-old cottonwood grove; level topography; 10 to 14 inches of dark grayish-black loam; dry; slightly prismatic, friable; fragments crush easily into small granules; a zone of root concentration; gives a positive, though not strong, reaction with HCl; 20 to 24 inches of chalky white calcareous clay loam; dry; somewhat compact; the upper part of this horizon has a granular structure; the lower part exhibits horizontal cleavage and lamellar structure; small vertical pores or tubes are numerous; some tree roots invade this layer; reacts strongly with HCl; 22 inches of dark yellowish-gray gravelly clay; sparingly banded with rust-colored gravel accumulations; moist; compacted to a panlike consistency; lamellar or platelike structure (horizontal cleavage); small vertical tubes abundant; a few tree roots get into this horizon; reacts strongly with HCl.

PHYSICOCHEMICAL PECULIARITIES

Some of the more important physicochemical characteristics of these profiles are presented in table 14.

TABLE 14.—*Some physicochemical characteristics of the soils of east-central North Dakota*

Profile no.	Depth	Soil moisture [1]	Volume weight	Texture	Reaction with dilute HCl
	Inches	*Percent*			
8	5	16.6		Loamy sand	None.
	23	12.1		Sandy loam	Moderate.
	37	12.3		Loamy sand	Strong.
	50	4.4		Sand	Weak.
11	8	15.8		Sandy loam	None.
	18	13.0		Loam	Do.
	35	7.2		Sand	Violent.
	50	3.7		do	Strong.
10	8	8.1		Loamy sand	None.
	23	7.8		Sandy loam	Weak.
	38	5.7		Sand	Moderate.
	50	2.5		Coarse sand	Do.
13	5	5.7	1.19	Loam	None.
	11	4.0	1.44	Loamy sand	Do.
	20	6.4	.97	Loam	Strong.
	35	5.2	1.56	Gravelly loam	Moderate.
	55	2.6	1.28	Coarse sand	Weak.
9	5	16.2		Loam	None.
	15	8.2		Gravelly loam	Do.
	30	10.0		Gravelly clay	Strong.
	50	17.0		do	Do.
14	4	10.4	.95	Loam	None.
	10	9.2	1.17	Silty loam	Do.
	20	16.9	1.32	Gravelly silt loam	Strong.
	48	17.2	1.64	Gravelly clay	Moderate.
15	4	12.0	.99	Loam	None.
	20	15.3	1.27	Clay	Strong.
	40	19.6	1.14	do	Moderate.
5	5	18.5		Loam	Weak.
	15	16.0		Clay loam	Strong.
	40	12.0		Gravelly clay	Do.
	60	15.1		do	Not tested.

[1] Calculated on the basis of oven-dry weight.

Two important facts are brought out by this table: (1) The soils of east-central North Dakota have a relatively high moisture content, and (2) they are characteristically carbonate-free in the surface or humous layer, and carbonate-rich in the horizons immediately below. In these respects they are similar to the chernozem soils of Russia.

Other field tests include the determination of the volume weight or apparent specific gravity of some[13] of the profiles studied. The volume weight or apparent specific gravity of soils is described by Curry (*5*) as "the ratio between the weight of a given volume of undisturbed water-free soil and the weight of an equal volume of water." All volume-weight determinations were made with a hollow-tube sampler fashioned from galvanized pipe. This sampling tube had an inside diameter of 3.96 cm and an inside length of 4.78 cm. Its volume calculated mathematically was 58.9 ml.

The volume-weight analyses for profiles 13, 14, and 15 show that the density of the upper 4 to 5 inches of these undisturbed soils is less than that of deeper horizons. Aside from this, there seems to be no common trend. Profiles 13 and 15 exhibit compactness in horizons intermediate between the shallowest and deepest layers, whereas profile 14 shows an increase in density with depth. Just what effect these natural differences in density have on tree growth in east-central North Dakota is not known.

As shown by the detailed profile description, one of the most characteristic physicochemical phenomena of the soils of central North Dakota is the occurrence of minute tubelike formations in the subsoil. Makhov (*14*) describes these carbonate tubes, and observed them at a depth of 35 to 50 inches in the chernozem of central Ukraine (the average annual precipitation of Ukraine varies from 16.5 to 21.5 inches). He also observed that these carbonate tubes were often accompanied by bands of small, scattered lime growths which he called "bieloglazka" (white eyes). These lime growths are commonly found in the soils of central North Dakota (see fig. 10) and form additional evidence of the physicochemical similarity of these soils to the chernozems of Russia.

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[13] Unfortunately no sampling tube was available when the first 12 profiles were examined.

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